Utilizing RFID-WSNs for Reducing the Footprint of the Oil Sands Industry

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*Abstract***— In harsh operational conditions, machines lose components on a frequent basis, causing a significant footprint to the surrounding environment. This affects operational up-time, safety measures and cost effectiveness. This paper proposes the use of an integrated RFID-WSN architecture to reduce the footprint of mining equipment used in the Canadian Oil Sands industry. Sensors and RFID tags provide both identification and positioning data for detecting broken parts from Ground Engaging Tools (GETs), such as huge shovel teeth. A delay-tolerant delivery approach utilizes mobile couriers, placed on loading trucks available in the vicinity, to store and carry data from readers and relays to remote base-stations. Delivering data in such harsh mining environments poses several challenges including power scarcity, vast transmission distances and the lack of an accessible communication infrastructure. We provide a use case to demonstrate how this architecture successfully overcomes these challenges within the harsh industrial environment of the Oil Sands.**

Keywords- RFID; wireless sensor networks; IoT; harsh environments; industrial waste; Oil Sands; mining

I. Introduction

The integration of wireless communication technologies into hybrid systems has been widely explored as a significant characteristic of future Internets. Particularly, the Internet of Things (IoT) has been introduced as an ultra-wide mesh of objects and virtual entities that are identifiable, tractable and connectable [1]. The IoT vision is expected to bring a new perspective to the way we interact with the environment around us on multiple levels including social, environmental, cultural and business. However, such a vision faces numerous challenges, especially in terms of compatibility among communication protocols (e.g. ZigBee, Bluetooth, WiFi, etc.).

According to IoT literature, Radio Frequency Identifiers (RFIDs) and Wireless Sensor Networks (WSNs) have been agreed upon as the most prominent components of this hybrid vision [2]. This is based on the simplicity of their design, inexpensive manufacturing and deployment costs, and their infrastructure-less nature. RFID and WSN couple the physical and virtual world in pervasive computing environments.

RFIDs provide convenient identification and positioning solutions [3]. They are of great use in industrial and supply chain management applications due to their extremely low cost and power requirements. RFID tags are classified into two categories active and passive. Active tags include a battery which allows long range communication up to several hundred meters. Passive tags harvest their power remotely from the reader and use back-scatter techniques to communicate with the reader which limits the communication radius up to several meters away from the reader. An RFID system is expected to perform with minor hindrances as long as its readers are accurately placed to insure proper coverage of all the tags within the premises, while avoiding reader-collisions. Nevertheless, RFID tags lack the ability to provide sensing information of their surroundings, which is a crucial requirement for monitoring industrial applications. In addition, RFID tags are restricted by single-hop communication links reducing the area of coverage. Wireless sensors, on the other hand, can provide readings on sensor elements such as temperature, light, force, pressure, altitude, humidity, etc. Sensor nodes can intercommunicate in a multi-hop fashion that facilitates diverse data delivery and could be used to enhance localization measurements. Moreover, sensor nodes may be equipped with buffering and processing capabilities that could be utilized in more advanced routing/delivery schemes. Thus, the integration of RFIDs and WSNs will increase their combined identification, sensing and delivery capabilities, resulting in heterogeneous systems that fulfill the aforementioned characteristics of the IoT vision.

A number of challenges face such integrated systems depending on the deployment settings. These challenges are prominently in the communication topologies and standards, in addition to the control protocols and the impact of their overhead on network operation. Such settings range from lively metropolitan regions to secluded rural areas, such as the Oil Sands. As an example of an application in the latter setting, we examine the process of extracting crude oil mixed with sand in northern Alberta, Canada. The oil extraction technique is established by mining the oil sand using large shovel tractors and trucks. The sand is transported to crushers to produce small chunks of manageable ores. The ores consistently flow onto vibration screens, where they mix with water and are pumped through the hydro-transport pipelines, which carry the mixtures to extraction facilities to produce crude oil.

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In harsh industrial environments such as Oil Sands, damage to sensors may occur because of: chemical spills, constant vibration, moisture, extreme temperature fluctuations over 50° C, sand abrasion, pressure forces, shocks from physical impacts, etc. Therefore, deployed sensors must be physically rugged, fault tolerant, ultra-low power, numerically abundant, and have a very low cost. Today, some industrial equipment and machinery in the Oil Sands are monitored manually, either by visual inspection, cameras, manual spreadsheet measurement logs, or during preventative maintenance cycles. These sensor-less equipment rely on expert operators and expensive monitoring equipment during maintenance phases to detect possible anomalies, yet irreversible damage may occur before a problem is detected by the inspector.

This paper discusses the use of our integrated RFID-WSN architecture to monitor the proper operation of shovel teeth crowns, or Ground Engaging Tools (GETs), during active operation on the shovel trucks. GETs are usually monitored manually by human visual inspection. However, a broken or lost GET may go unnoticed for several days. This is enough time for a lost GET to be buried underground for several weeks, or make its way to the crusher, where the extremely tough material of the GET can cause devastating damage throughout the extraction terrain. Thus, the retrieval of a lost GET reduces waste imposed by the equipment on the environment, its long-term footprint, and prevents any further damage to the ore crushing equipment.

The remainder of this paper is organized as follows. Section II discusses the background and related work in integrated architectures and harsh environments. Section III details the system architecture of the integrated RFID-WSN solution, elaborating on the network model, relaying and localization schemes. To demonstrate the utility of our approach, a use case is presented in Section IV, encompassing the different components of our system and their interplay in an Oil Sand field. Lastly, Section V presents conclusions and future work.

II. RELATED WORK

A. Integrated architectures

A variety of integration architectures have been proposed to join RFIDs and WSNs capabilities into a single system [4]-[8]. The architecture in [4] integrates sensors with RFID readers into a system that also assumes the existence of RFID tags and sinks or base-stations. The system is proposed for asset tracking. However, combining complex and expensive readers with each sensor over the entire deployment area imposes a considerable inflation in cost.

Another integration approach considers RFID tags and sensor nodes as distinct entities that operate independently [5]. In this architecture, the system includes three classes of devices: sensor nodes, tags, and smart stations. These latter devices consist of an RFID reader, a data microprocessor, and a network interface communicating with the network base-station. *SARIF*, a sensor and RFID integration framework following this architecture, was proposed in [6] as a middleware that operates on top of RFID and sensor networks to track environment-sensitive objects. This architecture, however, suffers from serious weaknesses due to its many-to-one traffic patterns. It also presents some problems related to energy imbalance among the smart nodes it introduces. We adopt an alternative approach proposed by Al-Turjman et al. [7] where RFID readers and relays are integrated into single entities called super nodes that incorporate most of the system's cost factor and relieve sensors and tags from any relaying tasks.

A third integration approach involves combining RFID tags and sensors together into single sensor-tag (ST) nodes [8]. This provides sensing capabilities to RFID tags and enables tags to inter-communicate with each other to form a multiple hop network. Moreover, ST nodes use the same RFID protocols and mechanisms for reading tag IDs as well as for collecting sensed data. Integrated ST nodes are used in a wide range of applications such as temperature sensing, PH value detection, location recording, vehicle-asset tracking and heartbeat rate monitoring, among many others [9]-[11]. We adopt this integration approach in the lower layer of our architecture, as later explained in Section III.

TempSens [9] is an application that periodically measures temperature in a configurable measurement interval. Its nodes use semi-passive tags and can be embedded in any product that could spoil during transport due to temperature fluctuations. Another temperature tracker developed by [10] integrates active tags with sensors. This system consists of three components: temperature-tracking tags, RFID Readers and *CertiScan* software, which runs on a standard Windows-based computer. Each tag is capable of receiving programmable temperature thresholds via two-way RFID communication. The LED indicator on the tag can blink with warning signals if temperatures exceed certain thresholds.

The two aforementioned applications utilize semi-passive and passive tags, respectively. However, passive tags with integrated sensors represent a more energy-efficient approach with temperature independent operation and longer lifetime. Such an approach is suitable for harsher deployment circumstances such as the one assumed in our architecture. Instrumental passive tags developed by *Instrumentel* [11] are capable of powering sensors and triggering actuators. The tags capture enough power from reader signals to drive integrated sensors. Unlike the sensors in an active tag, the sensor in an *Instrumentel* tag monitors the environment only when it is interrogated by a reader. In one of its applications, a tag with a PH sensor is placed into dentures and is used to monitor the level of acidity or alkalinity of food in the mouth of patients. The technology is suitable for a range of research applications, including securing medical specimens.

B. Sensor networks in harsh environments

At the Oil Sands mining location in Ft. McMurray, Alberta, we are currently monitoring the vibration screens used to filter large ores from the sand. We use our own WSN platform, called *Sprouts* [12] to monitor the thickness of the steel and tungsten layer of the vibration screen [13], as seen in Figure 1.

The Sprouts nodes relay the thickness data to a central node, which acts as a gateway to a 3G network. The central node is permanently powered by the vibration screen's AC power source, which allows us to monitor, maintain, and

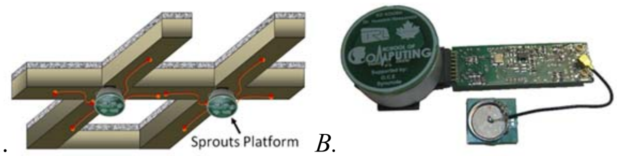

Figure 1. Sprouts nodes used to monitor the vibration screens are also used to monitor GETs: A. Vibrations screen cloth B. Sprouts sensor platform.

update the system remotely at any time. We remotely upload reported thickness data to a secure website where a graphical user interface (GUI) displays the health conditions of the vibration screen. In the proposed architecture, we leverage our currently established infrastructure at the vibration screen to service data collected from the shoveling site. The architecture allows transport trucks to act as mobile collectors and relay collected data every 20 minutes on average as they pass by the vibration screen.

C. Delay Tolerant Communication

Delay-Tolerant Networking (DTN) is characterized by the absence of coexistent end-to-end links between node pairs in a given setting [14]. This results in the need to store messages at source or intermediate nodes for intervals exceeding conventional IP time-to-live (TTL), until the message's intended destination is encountered or a suitable forwarding opportunity arises.

In general, DTN routing schemes adopt a Store-Carry-Forward (SCF) approach that utilizes different queuing management policies [15]. There has been numerous DTN routing proposals [16]. DTN routing scheme may adopt random, probabilistic or direct delivery approaches. Nevertheless, forwarding decisions are based on the level of knowledge available (i.e. zero, partial or full) regarding nodes' mobility and their encounter-rate. The MCs in our architecture perform SCF routing. The efficiency of their delivery is highly dependent on the predictability of their mobility patterns. As explained in use case Section IV, this turns out to be quite deterministic in Oil Sands settings.

D. Localization in harsh environments

Localizing and tracking lost GETs, or broken shovel teeth, is the objective of the proposed architecture. However, in harsh environments, the surrounding conditions are not recommended (or rated) for operating sensor nodes or RFID tags. Therefore, GETs localization methods need to overcome performance-hindering factors to maintain an acceptable accuracy and precision level.

An Oil Sands field is a harsh environment for localization due to the severe RF signal distortion and attenuation. Shadowing and multipath propagation of the signal due to the reflections from the trucks, shovels, and terrain is a major challenge to the different localization schemes that are based on angle of arrival (AoA) and time difference of arrival (TDoA) [3].

Buried teeth represent a second challenge to be addressed in the localization scheme by analyzing the RF propagation properties and minimum signal strength at the RFID reader or sink node. The third challenge is the orientation of the tooth especially that the sensor node will be embedded inside the tooth, as seen in Figure 2, which force the signal to have a directional beam-form with limited strength due to the metallic object. Deploying anchor nodes as in scene analysis localization mechanisms [17], [18] is also an unfeasible solution due to the dynamic movement of the readers and sink nodes, which limits the mapping of the signal at the anchor nodes to the expected location.

To address these challenges, more readers and sink nodes are required to accommodate the weak and scattered signal from the different nodes. In addition, more than one antenna at the node would augment the received power at the reader and minimize signal directivity. Received Signal Strength Indicator (RSSI) based mechanism provides an attractive solution due to the reasonable reliability of RSSI measurements in long-range transmissions [19]. Another considered solution, especially for passive RFID tags, is range estimation using power-optimized waveforms (POW) [19], where the node's range can be estimated by cross correlating the received reflection of the POW pulses with the original transmitted by the reader.

As we will describe in the next section, our architecture relies on both RFID and WSN signals emitted by its ST nodes to further enhance the localization process. It is important to note the role of integrating multiple readers/relays, to improve the accuracy of localization by means of more precise multilateration.

III. System Architecture

A. Network Model

We adopt a four-layered hierarchical architecture for detecting broken Ground Engaging Tools (GETs) in the Oil Sands mining locations of northern Canada. Our integration and deployment approach address the intense energy and communication constraints enforced by such a harsh environment.

- The upper layer of our architecture represents base-stations that act as sink nodes delivering all data collected by the lower layers to the control headquarters.
- The lower layer of our architecture consists of simple *Sprouts* nodes that coexist as integrated ST nodes. These nodes are fully dedicated to performing identification and sensing operations and are relieved from conducting any relaying or processing tasks, which in return minimizes their circuitry design and prolongs their operational lives. ST nodes are relatively cheaper to deploy abundantly and have a minor impact on network cost.

A.  B.

Figure 2. A. Ground Engaging Tool (GET), or shovel tooth B. Location of Sprouts sensor platform inside the GET

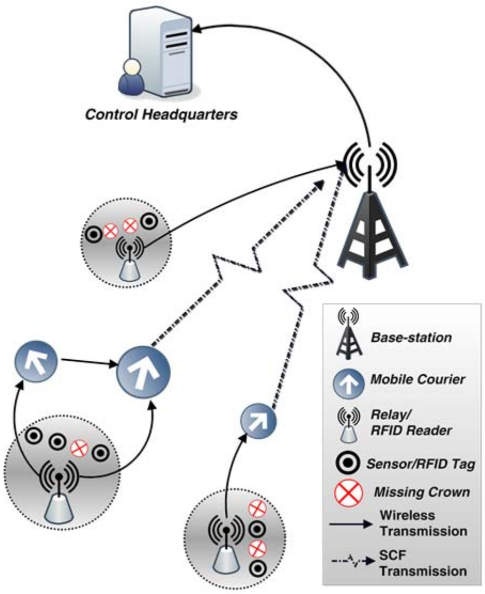

Figure 3. Integrated RFID-WSN architecture

- Immediately above the ST layer resides a second integrated layer of Reader/Relay (RR) nodes. RRs are required to perform communication protocols necessary to confirm the existence and read the data collected by both ST components, in addition to periodically relaying this data to top-layer's base-stations. This approach was originally proposed in [7] to dominate the cost factor by distributing the sensing and relaying loads over the components of integrated networks in an optimum fashion. The absence of a communication infrastructure in the suggested setting validates our selection of this minimal deployment approach.

- Links between the RRs and the base-stations represent the only means of delivering the data reported by ST nodes at the lower layer. Such a setting is highly vulnerable to disconnectivity and partitioning effects, especially in scenarios where RRs are static. Henceforth, we introduce the middle layer of our architecture, the Mobile Couriers (MCs). MC nodes represent transport vehicles, such as the sand transport trucks, or any mobile entity equipped with transceivers. MCs are assumed to vary in their buffering, processing and transmission capabilities while existing abundantly in an IoT setting. Thus, they represent a choice as linkers between RR nodes and base-stations whenever disconnection occurs between these two tiers. An MC is moving according to a fixed mobility trace towards a base-station. It conducts SCF until a best-next-hop is found. MCs are capable of inter-communication to carry their data loads and, if residual energy permits, may even assume the role of relays and directly transfer the data load to base-stations.

Figure 3 illustrates our proposed integration architecture ST nodes reside on the lower layer, such that their data loads, both singular and aggregated, are exclusively gathered by the second integrated level of the architecture, the RRs. The reader component of the RRs ensures their efficient deployment to fully cover the RFID tags in the topology.

The Oil Sands targeted application serves this particular constraint, as will be elaborated upon in Section IV. The relay component, on the other hand, is requested to deliver the data to the base-stations. However, in case a base-station is out of reach, MCs conduct the role of linkers between the RR and the base-station.

B. Relaying protocols

When an ST node is ready to transmit a packet (e.g. when the monitored component breaks off), a beacon is transmitted to search for the closest RR node. Once found (by an ACK message), the ST forwards the data packet to that RR node. It is important to note that no arbitration takes place at this phase. The first RR node to be found will receive the packet, as the transmission impact on the ST is too significant to allow for retranmissons or searching for the best next hop. After the first RR receives the data load, it will attempt to beacon the base station.

If a response is received, the data load will be sent right ahead, to save the overload of multi-hop communnication and the due contention on the medium. However, if that attempt times out (a threshold is adapted to each environment for an appropriate timeout), then the RR node will broadcast a request to SCF for nearby RR nodes. Contention at this point will depend on residual energy on receiving RR nodes, and their destination. At this stage, a binary flag of whether the MC to SCF the message is heading towards or returning from the BS.

Algorithm 1 details the process of initial transmission of a report ***R*** from the ST that generated it. Each hop to follow, towards the sink, will follow the protocol presented in Algorithm 2.

Algorithm 1: Reporting protocol - ST

Input: report ready from ST

Procedure ST_Report( )
1. R ← report message
2. Broadcast(REQ)
3. While NOT (ACK received from node $\boldsymbol{n_i}$)
4. wait (τ)
5. else
6. Unicast(R, $\boldsymbol{n_i}$)

Algorithm 2: Forwarding protocol - RR

Input: message ***R*** at current RR to fwd to BS

Procedure RR_Forward( )
1. **BS**.dist ← ∞
2. **BS**.direction ← 1 //i.e. towards BS, 0 reflects a MC coming from the BS
3. **BNH ← BS** //BNH reflects best-next-hop
4. Broadcast(REQ)
5. For each (ACK from n_i)
6. If n_i.dist < BNH.dist AND n_i. direction = 1 then
7. BNH ← n_i
8. Unicast(***R***, BNH)

C. Localization Schemes

To localize a broken tooth, we propose an RSSI-based method. We utilize multilateration through adjustable RF power levels of RR nodes to determine their location. ST nodes are equipped with three independent antennas probed into the tooth with asynchronous transmission. The collected RSSI values by a minimum of three RR nodes will localize the tooth in two dimensions. The measured RSSI values will be mapped to absolute distances that are considered the radius - where the RR node is at the center- as shown in Figure 4. The intersection region between the three circles estimates the location of the ST node. Each ST node is equipped with three independent transceivers, which are activated once a GET is disconnected from the shovel. Hence, the RR node will receive three RSSI readings from each ST to increase the reliability of the estimation scheme.

In the field, mobile couriers (i.e. trucks) have a known absolute position through GPS to work as reference nodes for absolute location estimation of the tooth. In addition, anchor RR nodes are placed at fixed and pre-determined locations to assist the reference nodes on the trucks. Similar to the embedded ST in the tooth, the anchor nodes also provide RSSI values to the sink nodes on the trucks. However, their RSSI indicate the terrain effect and shadowing when the truck is at that specific location. If the RSSI from the anchor node matches the known distances between the anchor node (fixed and pre-determined by GPS) and the truck (by GPS), then that truck is considered at a better location for localization (i.e. experiencing less shadowing and terrain effect) than another truck with incorrect RSSI reading. Consequently, relaying MCs that received more RSSI values matching the distance with anchor nodes are considered for localizing the tooth. Since each ST is providing three RSSI values, the localization scheme will take the average of the multilateration calculation to be the expected location of the tooth. In case of a dead ST, multilateration based on RFID tags in the ST is considered for localization. The power levels from the RR reader are increased (with fixed steps) until the ST is detected. That power level is then mapped to the appropriate distance that will be considered as the radius for multilateration calculations.

IV. USE CASE: GET RETREIVAL

The major challenge we address in this paper is locating industrial waste lost in mining locations in the Oil Sand extraction industry. We introduced an integrated RFID-WSN architecture to track and locate lost GETs that break during the process of shoveling. Fallen teeth (accidentally) transported in oil sand to the vibrating screens may result in damages to the machinery and cause additional maintenance, repair, and downtime costs. Abandoning these shovel teeth in the ground, on the other hand, may have a negative impact on the environment. Such industrial waste may contaminate the soil and water if left without retrieval, resulting in a significant environmental footprint.

We map our four-tier integrated architecture to the components of an excavation site. Our mapping takes into account harsh environmental challenges, transportation delays, and lack of a communication infrastructure imposed by the setting. As described in Section I, damages to sensors may occur. Therefore, deployed STs must be physically rugged. Such a constraint is well addressed by the *Sprouts* WSN platform. Adding an RFID-tag circuit to this design requires a slight modification of the circuitry and yields our ST integrated nodes, which represent the lower layer of our architecture.

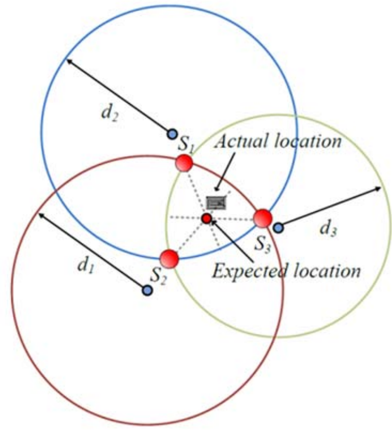

Figure 4. Multilateration technique with three readers to localize a tag

Figure 5 depicts the components of our architecture mapped to an excavation site setting. A typical site includes a) digger with GET components b) trucks to transport the excavated oil-sand and c) a vibrating screen. We mention that there are many associated delays in the above scenario. A round trip for a single truckload may take between 15 to 30 minutes. A broken GET may get lost in the underground for several weeks. Based on this setting, ST nodes of our integrated architecture are mounted inside the GET, as seen in Figure 5. The RR (Relay\Reader) node is mounted on the body of the tractor. This deployment ensures that the RFID reader and tags are able to periodically communicate within the reader's interrogation zone. Hence, RFID tags will provide identity to each GET tooth. In case of a breakage, the loss is immediately detected by the reader.

The relay part of the RR unit transmits this data to the base-station, which is attached to the vibration screen, due to the availability of an AC power source. Vibration screens represent the main hub of the excavation setting where the majority of the sites infrastructure is available. However, two concerns arise regarding a successful communication between the RR and the base-station in the above scenario. First, the location of the RR's single-source signal might be misleading to the base-station and considerably lacks accuracy without multilateration. Second, given the vast distance separating the digger and the vibration screen in typical excavation sites, an RR might not have sufficient power or transmission capabilities. To address these two concerns without violating our cost efficiency constraints, we utilize the trucks (heading to BS) usually located around the diggers as MCs that will relay the RR's message, as highlighted in Algorithm 2. In addition, MCs participate in locating the source of the broken tooth accurately using both its RFID and WSN signals, via multilateration.

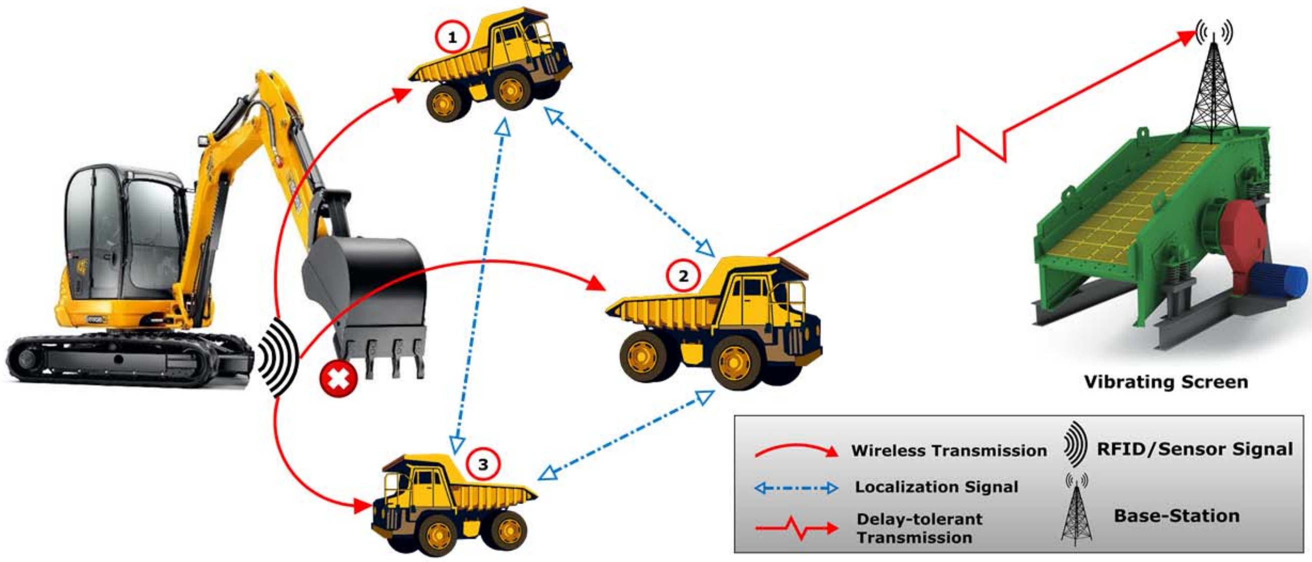

Figure 5. Use case demonstrating the utility of our RSN-WSN architecture for Canada's Oil Sands process

V. CONCLUSIONS

State of the art technologies on communication and localization still face major challenges in industrial environments. We present an integrated architecture of RFID and WSN nodes, to deliver a system that is able to detect the breakage of industrial components, and localize them for efficient retrieval. A major challenge in harsh industries is the operational condition and frequency of damage to different components. Moreover, the remote sites and zero-tolerance to downtime render such a challenge more difficult. We present a model that caters to dynamic detection, and real-time forwarding of data messages in large fields utilizing the mobility of its machinery. As such, the system utilizes its own components to relay messages and reports to control personnel, without the need, and current practice, of visual monitoring. We presented an elaborate use case elaborating on the utility of this architecture in the oil-sand extraction industry.

VI. ACKNOWLEDGMENT

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REFERENCES

[1] L. Atzori, A. Iera and G. Morabito, "The Internet of Things: A survey," in *Computer Networks*, vol. 54, no. 15, pp. 2787-2805, October 2010.

[2] A. Evangelos, A. Kosmatos, N. Tselikas, "Integrating RFIDs and Smart Objects into a Unified Internet of Things Architecture," in *Advances in Internet of Things*, vol. 1, no. 1, 2011, pp. 5-12.

[3] M. Bouet, A. L. dos Santos, "RFID tags: Positioning principles and localization techniques", in *1st IFIP Wireless Days*, Nov. 2008, pp.1 – 5.

[4] A. Mason, A. Sha, A. I. Al-Shamma'a, "Asset Tracking: Beyond RFID", PGNET, in *7th Annual PG Symposium on the Convergance of Telecommunications, Networking and Broadcasting*, 2006, pp. 267-272.

[5] L. Zhang, and Z. Wang, "Integration of RFID into Wireless Sensor Networks: Architectures, Opportunities and Challenging Problems", in *Proc. Intl. Conf. on Grid and Cooperative Comp*, Changsha, Hunan, 2006, pp. 463-469.

[6] J. Cho, Y. Shim, T. Kwon, Y. Choi , "SARIF: A Novel Framework for Integrating Wireless Sensor and RFID Networks," in *IEEE Wireless Communications*, vol.14 no. 6, Dec. 2007, pp. 50-56.

[7] F. Al-Turjman, A. Al-Fagih and H. Hassanein, "A Novel Cost-Effective Architecture and Deployment Strategy for Integrated RFID and WSN Systems," in *Proc. IEEE Intl. Conf. on Computing, Networking and Communications*, Maui, Hawaii, 30 Jan.- 2 Feb. 2012, pp. 835-839.

[8] A. G. Ruzzelli, R. Jurdak, and G.M.P. O'Hare, "On the RFID Wake-up Impulse for Multi-hop Sensor Networks", in *Proc. ACM Workshop on Convergence of RFID and Wireless Sensor Networks and their Applications*, Sydney, Australia, 2007.

[9] http://www.kswmicrotec.de

[10] http://www.americanthermal.com

[11] http://www.instrumentel.com

[12] A. El Kouche, "Towards a Wireless Sensor Network Platform for the Internet of Things," in *Proc. IEEE Intl. Conf. on Communications (ICC)*, Ottawa, Canada, June 2012, pp. 642-646.

[13] A. El Kouche, L. Al-Awami, H. Hassanein and K. Obaia, "WSN application in the harsh industrial environment of the oil sands," in *7th Intl. Wireless Communications and Mobile Computing Conf. (IWCMC),* July 2011, pp. 613-618.

[14] C. Caini, H. Cruickshank, S. Farrell, and M. Marchese, "Delay-and Disruption-Tolerant Networking (DTN): An Alternative Solution for Future Satellite Networking Applications," in *Proc. IEEE*, vol. 99, no. 11, Nov. 2011, pp. 1980 –1997.

[15] S. Jain, K. Fall and R. Patra, "Routing in a Delay Tolerant Network," in *Proc. ACM SIGCOMM Communication Review*, 2004 pp. 145-158.

[16] Z. Zhang, "Routing in Intermittently Connected Mobile Ad Hoc Networks and Delay Tolerant Networks: Overview and Challenges," in *IEEE Communications Surveys*, vol. 8, no.1, 1st Quarter 2006.

[17] C. Wang, H. Wu, and N.-F. Tzeng. "RFID-Based 3-D Positioning Schemes," in *Proc. INFOCOM 2007*, pp. 1235–1243.

[18] L. M. Ni, Y. Liu, Y. C. Lau and A. P. Patil, "LANDMARC: Indoor location sensing using active RFID," in *Proc. IEEE Intl. Conf. on Pervasive Computing and Communication*, 2003, pp. 407-415.

[19] P. Kumar, L. Reddy, S. Varma, "Distance Measurement and Error Estimation Scheme for RSSI Based Localization in Wireless Sensor Networks," in *IEEE Conf. on Wireless Communication and Sensor Networks* (WCSN), Dec. 2009, pp.1-4, 15-19.

[20] M. S. Trotter and G. D. Durgin, "Range Estimation for Passive RFID Systems That Use Power-Optimized Waveforms," in *IEEE Intl. Conf. on RFID*, Apr. 2012, pp. 149-156.